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National Aeronautics and
Space Administration

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DIGITAL TELEVISION STANDARDS FOR NASA

NASA TECHNICAL STANDARD

FOREWORD

This standard is approved for use by NASA Headquarters and all NASA Centers and is intended to provide a common framework for consistent practices across NASA programs.

This standard was developed to assist the development and implementation of digital television systems that support the NASA by the NASA Digital Television Working Group (DTVWG) and by the NASA Principal Center for Communications Architecture (PCCA).

Since the late 1980s, the technology and equipment used for the acquisition, production and distribution of television has been moving from the traditional world of analog signals, recording formats and signal processing into the digital realm. Digital video systems, starting with cameras and recorders for image acquisition, through systems for program production, to final signal distribution are already in use in many television facilities. The commencement of commercial terrestrial DTV broadcasting in 1998 signified the general availability of end-to-end DTV capability in the United States.

The U.S. standard for terrestrial DTV broadcasting established by the Federal Communications Commission (FCC) is based on work recorded in document A/53 prepared by the Advanced Television Systems Committee (ATSC). In addition to specifying a method for broadcasting a digital representation of the traditional U.S. 525 line interlace scan television format, the ATSC A/53 standard detailed many new television formats and variations for both Standard and High Definition Television (SDTV and HDTV). While the FCC adopted most aspects of the ATSC standard when it established the standard for U.S. DTV broadcasting, it declined to specify the use of any particular picture format or formats. However, the ATSC standard formats are generally regarded and accepted in the television industry as the formats to be used for broadcasting. The result of this action has been that instead of just one format of television for all uses, there are now many different available types and levels of quality of DTV.

During the era of a single analog U.S. standard video signal format, ANSI/SMPTE 170M-1994, there has been no real need for NASA to develop agency-wide television signal standards. The fact that there are so many new and different digital television signal formats and methods now available has shown the reason for NASA to establish signal standards for DTV. These standards are needed so there may be common methods developed for the acquisition and production of DTV information and for the distribution and interchange of DTV signals and video products within, and external to, the agency.

Requests for information, corrections, or additions to this standard should be directed to the Marshall Space Flight Center, Mail Code AD30. Requests for general information concerning standards should be sent to the NASA Technical Standards Program Office, ED41, MSFC, AL, 35812 (telephone 256-544-2448). This and other NASA standards may be viewed and downloaded, free-of-charge, from our NASA Standards Homepage: http://standards.nasa.gov.

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DIGITAL TELEVISION STANDARDS FOR NASA

1. SCOPE

1.1 Scope. The video system standards described in this document are related to those industrial or professional systems used to produce full motion and full resolution digital video that is suitable for critical closed circuit or broadcast use and which is normally distributed over wide bandwidth communications systems designed for video. It is not the intention of the Digital Television Working Group (DTVWG) to imply or endorse the use of any specific commercial vendor standards, designs or hardware.

For the purposes of this document, the uses for video acquisition, production, and distribution within NASA are considered as falling into one of two broad categories: Analysis and Program. Analysis video is defined as video imagery that is acquired primarily for the purpose of being used by NASA or other authorized personnel, either in real-time or post-event, to observe, analyze, or document a NASA activity. Examples include space launch and space flight activities, flight vehicle tests, laboratory and facility testing, scientific experiments, and training activities. Program video is defined as video imagery that is acquired primarily for the purpose of being integrated into live video segments or edited programs that are created for disseminating information concerning NASA activities within the agency and/or for release to the news media or the public. Examples of these programs include educational videos, training videos, televised management briefings, video-file material, live-shots, press conferences, and video coverage of other NASA events. It is noted that many of these video programs may be produced partially or in their entirety using video imagery generated by analysis or joint use video systems or by using source material that was originally acquired for analysis purposes.

These standards shall apply to all NASA center video systems infrastructure used to acquire and produce analysis and program video. It is recognized by the DTVWG that the specific analysis needs or unique constraints associated with certain flight, test or laboratory related video may prevent those systems from precisely adhering to this standard. In these cases, those projects shall be required to either convert their video signals or products to meet the NASA infrastructure standards at an interface point or to provide separate systems to satisfy their unique video signal processing, recording and display requirements.

This document does not, at this time, discuss standards for the implementation of digital video other than full motion and full resolution or which uses other than wide bandwidth communications systems. This includes systems such as are used for reduced resolution video used for teleconferencing systems, for the streaming of live video or on-demand video segments over a computer intranet or the Internet and for dial up or Internet distribution of surveillance video.

1.2 Applicability. This standard recommends engineering practices for NASA programs and projects. It may be cited in contracts and program documents as a technical requirement or as a reference for guidance. Determining the suitability of this standard and its provisions is the responsibility of program/project management and the performing organization. Individual provisions of this standard may be tailored (i.e., modified or deleted) by contract or program specifications to meet specific program/project needs and constraints.

2. ACRONYMS AND DEFINITIONS

2.1 Acronyms

2.1.1	AES	Audio Engineering Society
2.1.2	ANSI	American National Standards Institute
2.1.3	ATSC	Advanced Television Systems Committee
2.1.4	CCD	Charge Coupled Device
2.1.5	CODEC	enCOder/DECoder
2.1.6	DCT	Discrete Cosine Transform
2.1.7	DTV	Digital Television
2.1.8	DTVWG	Digital Television Working Group
2.1.9	DVD	Digital Versatile Disk
2.1.10	FCC	Federal Communications Commission
2.1.11	GOP	Group Of Pictures
2.1.12	HDSDI	High Definition Serial Digital Interface
2.1.13	HDTV	High Definition Television
2.1.14	MPEG	Moving Pictures Experts Group
2.1.15	SDI	Serial Digital Interface
2.1.16	SDTV	Standard Definition Television
2.1.17	SMPTE	Society of Motion Picture and Television Engineers

2.2 Definitions.

2.2.1 Acquisition. Initial capture of video imagery.

2.2.2 Acquisition Equipment. Equipment used for initial capture of video imagery. It can be production quality, but in the case of High Definition Television (HDTV) field camcorders, often has to compromise some image quality in order to have a one-piece camcorder configuration.

2.2.3 Analysis video. Video used, either in real-time or post-event, to observe, analyze, or document an activity.

2.2.4 Distribution Level. Lower quality video distribution between facilities acceptable for viewing, but not production or post-production.

2.2.5 Interlace Scan. Video scanning method where the scan lines that comprise an image are divided into two fields, one field consisting of the odd numbered scan lines, the second consisting of the even numbered scan lines. Interlace scanning was introduced in 1941 to refresh television screens 60 times per second while acquiring images at a rate of 30 frames per second. Generally referenced to as 2:1 scanning.

2.2.6 HDTV (High Definition Television). Video with $\geq$ 720 active scan lines.

2.2.7 Pixel. In digital television, the smallest picture element that can be resolved.

2.2.8 Production, Post-Production. Manipulation of images by switching, special effects, or editing to create a video program. Production is generally real-time creation with immediate release. Post-production is not real-time and is associated with editing for creation of the video program.

2.2.9 Production Equipment. Highest Quality equipment used for live programming or manipulation of video imagery after acquisition (post-production)

2.2.10 Program Video. Video acquired primarily for the purpose of disseminating information concerning NASA activities to the news media and the public.

2.2.11 Progressive Scan. Video scanning method where each scanning line is sampled and displayed sequentially, without dividing a video frame into fields (see Interlace Scanning). Generally referenced to as 1:1 scanning.

2.2.12 Scan Line. Smallest vertical unit of a video picture, which runs horizontally across the screen. Pixels make up scan lines.

2.2.13 SDTV (Standard DefinitionTelevision). Video with <720 active scan lines. For U.S systems, this is 480 or 483 active scan lines.

2.2.14 Video Frame. Total scan lines that comprise a complete video picture analogous to a frame of film in a motion picture.

3. NASA Digital Television (DTV) STANDARDS.

This document establishes three major categories of NASA Digital Television (DTV) standards:

- Acquisition and Production Picture Formats
- Video/Audio Signal Sampling Representation and Compression for Recording and Data Transfer
- Interfaces

The DTVWG has engaged in considerable analysis, testing and debate regarding these areas and has arrived at the conclusions detailed in this section. Rationale for these choices is contained in the appendices to this document.

The referenced applicable standards have been published by the American National Standards Institute (ANSI), the Society of Motion Picture and Television Engineers (SMPTE), the Audio Engineering Society (AES) and the Moving Picture Experts Group (MPEG).

3.1 Acquisition and Production Picture Formats

TABLE I. High Definition Television

ACTIVE PICTURE PIXEL SIZE (H x V)	PICTURE ASPECT RATIO	SCANNING METHOD	FRAME RATE	APPLICABLE STANDARD
1280 X 720 (Square Pixel)	16:9	Progressive 1:1	59.94 Hz	SMPTE 296M-1997

TABLE II. Standard Definition Television

ACTIVE PICTURE PIXEL SIZE (H x V)	PICTURE ASPECT RATIO	SCANNING METHOD	FRAME RATE	APPLICABLE STANDARD
720 X 483* (Non-Square Pixels)	4:3 or 16:9	Interlace 2:1	29.97 Hz	ANSI/SMPTE 125M-1995 (4:3) ANSI/SMPTE 267M-1995 (16:9)

*Active picture pixel size may be 720 x 480 for some specific recording formats.

3.2 Video/Audio Signal Sampling Representation and Compression for Data Transfer and Recording

TABLE III. Full Bandwidth Signal Transmission – HDTV and SDTV

FORMAT	DATA RATE	WORD LENGTH	APPLICABLE STANDARD
HDTV	1483.5 Mbps	10 bit	SMPTE 292M-1996
SDTV (Interlace)	270/360 Mbps	10 bit	ANSI/SMPTE 259M-1997 Levels C & D

TABLE IV. Signal Sampling Representation – HDTV and SDTV

FUNCTION	SIGNAL SAMPLING REPRESENTATION	WORD LENGTH
Acquisition	Chroma sampling on every video line: 4:2:2, 4:1:1, 3.1.1, etc. per the specific format. Luminance or chroma sub-sampling, or resolution filtering may be performed per the specific format	8 bit minimum
Video Editing and Duplication Using Acquisition Formats	"Cuts Only" editing and duplication may be done using acquisition format if it transfers the recorded bit stream unaltered in a "dub" mode such that no decoding and re-encoding of the signal is required.	8 bit minimum

TABLE IV. Signal Sampling Representation – HDTV and SDTV (CONT'D)

FUNCTION	SIGNAL SAMPLING REPRESENTATION	WORD LENGTH
Production and Post Production	4:4:4 or 4:2:2; No subsampling of luminance or resolution filtering	8 bit minimum
Intra-Center Transfer for Contribution	Any component signal representation which meets user defined requirements	8 bit minimum
Inter-Center and External Transfer for Contribution	4:2:2; No luminance or chroma sub-sampling (below 4:2:2), no resolution filtering	8 bit minimum
Distribution for Viewing	4:2:0	8 bit
Archiving	Original acquisition format for original material or "cuts only" material edited in an acquisition format, Production format for completed video programs.	8 bit minimum

TABLE V. Compression for Data Transfer and Recording – HDTV and SDTV

FUNCTION	COMPRESSION
Acquisition	Dependent upon the characteristics of the specific recording format, but shall be intra-frame based, with no less than 100 Mbps video data rate for HDTV and no less than 25 Mbps video rate for SDTV.
Video Editing and Duplication Using Acquisition Formats	"Cuts Only" editing and duplication may be done using acquisition format if it transfers the recorded bit stream unaltered in a "dub" mode such that no decoding and re-encoding of the signal is required.
Production and Post-Production	Less than or equal to 5:1, Intra-frame compression
Intra-Center Transfer	User requirement defined
Inter-Center and External Transfer for Contribution	HDTV - MPEG-2 4:2:2 Profile @ High Level, GOP size less than or equal to 15 frames, Video data rate greater than or equal to 32 Mbps. SDTV - MPEG-2 4:2:2 Profile @ Main Level, GOP less than or equal to 15 frames, video data rate greater than or equal to 8 Mbps.
Distribution for Viewing	HDTV, MPEG-2 Main Profile @ High Level, GOP size user defined, Video data rate greater than or equal to 12 Mbps. SDTV, MPEG-2 Main Profile@Main Level, GOP size user defined, video data rate greater than or equal to 3 Mbps.
Archiving	Original acquisition format for original material or "cuts only" material edited in an acquisition format, Production format for completed video programs.

TABLE VI. Audio Signal Sampling Representation and Compression

FUNCTION	APPLICABLE STANDARD
Acquisition	**AES-3, 48 kHz sampling**
Production and Post-Production	**AES-3 or pending AES/SMPTE standard for multi-channel production audio compression for digital video recorders**
Intra-Center Transfer for Contribution	**User requirement defined**
Inter-Center and External Transfer for Contribution	**MPEG Layer 2 @ data rate of greater than or equal to 128Kbps per channel**
Distribution for Viewing	**ATSC/Dolby AC-3 (Dolby Digital)**
Archiving	**AES-3 or pending AES/SMPTE standard for multi-channel production audio compression for digital video recorders**

3.3 Interfaces. Standardized data transfer interfaces need to be established for distribution of digital video within and between the NASA Centers and for the release of digital video to external NASA customers, the news media and the public. Interfaces are also needed for receiving digital video from flight vehicles such as the Space Shuttle and the International Space Station (ISS). Specification of these interfaces are being left as To-Be-Determined at this time. Each application of interfaces will be developed specifically to that application, based on the standards listed above.

APPENDIX A

DISCUSSION OF PICTURE FORMATS

HDTV

In making the choice of an HDTV format for NASA, several constraints, both real and assumed, were considered. One assumed constraint is that equipment would typically not work to more than one format, so a single HDTV picture format standard would need to be chosen. Another constraint, given existing standards, is the need to be able to transfer signals using equipment which conforms to the SMPTE 292M-1996 High Definition Serial Digital Interface (HDSDI). Another desire is to assure compatibility with the broadcast television community by choosing from among the picture formats defined by the Advanced Television Systems Committee (ATSC).

As defined by the ATSC, HDTV has three major picture formats:

- 1920 X 1080 interlace scan @ 30 frames per second (FPS) (1080I@30)
- 1920 X 1080 progressive scan @ 24 or 30 FPS (1080P@24/30) and,
- 1280 X 720 progressive scan @ 24, 30 or 60 FPS (720P@24/30/60).

All HDTV formats use square pixels and a 16:9 image aspect ratio. Interlace scan HDTV was first developed in the late 1970's. It was initially an analog method with 1125 total lines per frame of which 1035 were active image lines. The image is scanned using a two to one interlace method similar to the existing 525 line system. With this method, two fields, one for the even numbered lines and on for the odd lines, are scanned to created each video frame. This method provides a display refresh rate that is twice the actual frame rate. The 1125 line interlace method was adapted for digital use by increasing the number of active image lines to 1080. Since this format has existed for some time, there is a considerable amount of interlace HDTV equipment currently available. With the progressive method, each complete video frame is created in one continuous scan. The refresh rate using the progressive scan method is normally the same as the frame rate. The development of progressive scan DTV has been more recent, thus there is a more limited, but growing, amount of progressive scan HDTV equipment available. All of these formats can use equipment conforming to the Society of Motion Picture and Television Engineers (SMPTE) 292M-1996 HDSDI standard for data transfer.

A series of tests were conceived and conducted by the DTVWG to compare available interlace scan and prototype progressive scan HDTV equipment. The 1080I@30 and 720P@60 formats were compared. A report on the results of these tests can be found on the NASA DTV web site (www1.msfc.nasa.gov/DTV), or can be obtained from the NASA DTV Office (dtv@msfc.nasa.gov). The tests demonstrated comparable resolution and quality of the two formats when images were viewed in real time. Interlace video displayed some image artifacts that are introduced by the scanning method, but these are not significant for most general viewing. No similar artifacts appeared to be introduced by progressive scanning. However, when the video was captured and analyzed in still frame (and additionally in still field for interlace video), significant differences between the scanning methods became apparent. It was shown that interlace artifacts can alter the appearance of an object. It has been determined by research, and manufacturers of interlace HDTV cameras, that the scanning characteristics of the Charge Coupled Device (CCD) image sensors used in all interlace HDTV cameras cause considerable distortion of fine detail image material that appears 1-2 video lines (pixels) tall. While progressive scan cameras also use CCD sensors, the scan characteristics are not the same and the same distortions do not occur. Additional tests were performed to assess the results of transcoding from one format to the other. These tests showed that progressive scan source video transcodes to interlace without generating additional artifacts, but that artifacts existing in interlace scan source video carry over when transcoded to progressive. Both formats produced excellent results when down converted to 525 line interlace scan video. The artifacts associated with interlace scanning effectively negate the originally expected resolution advantage of 1080I@30 over 720P@60. The results of this testing plus knowledge gained from other research has proven to the DTVWG the general superiority of the progressive scan method over the traditional interlaced method for HDTV acquisition and production. It is also generally accepted within the television production and broadcast communities that progressive scan master recordings are superior for transcoding to all DTV formats. Thus, progressive scan HDTV was chosen by the DTVWG to ultimately be the NASA standard.

Some within NASA have suggested the initial use of 1080I HDTV equipment and then to transition to a progressive format. It has been argued that interlace equipment is already widely available, that 1080I provides much higher spatial resolution than existing National Television Standards Committee (NTSC) and that the 60 Hz field rate provides high temporal resolution. This course of action is not recommended by the DTVWG because of the issues associated with interlace scanning, the demonstrated advantages of progressive scanning and of the problems and expense that would be associated with performing an additional format transition. The DTVWG recommends no further acquisition of interlace scan only HDTV equipment and limiting the use of this format to that equipment which may have already been purchased within the agency. The DTVWG recommends proceeding directly to the use of a progressive scan HDTV format standard.

The DTVWG considered the use of the 1920 X 1080 progressive @ 60 FPS (1080P@60) format (the “Holy Grail” of HDTV). 1080P@60 is defined under SMPTE 274M but was not included as one of the ATSC standard formats. No equipment is currently available that supports this format, or is expected to be any time soon. Use of this format with current technology would require either the use of a form of mezzanine compression, which up until now has been shown to be economically impractical, or for the television industry to develop a new serial digital interchange standard based on a data transfer rate of approximately 3Gbps. Thus, 1080P@60 is not to be considered further at this time, but will be re-investigated in the future and could be incorporated into the NASA DTV standard if future developments allow the use of this format.

The task now was to choose a progressive scan format which, assuming a long-term goal of migrating to 1080P@60, may be considered an interim HDTV format. However, a consideration needed to be that this might also remain the permanent NASA HDTV format if 1080P@60 does not become a practical alternative in the future. The choice appeared to be between 1080P@24/30, which favors higher spatial resolution, or 720P@60, which favors higher temporal resolution.

The DTVWG noted that few currently available HDTV displays have the resolution capability to be able to show a dramatic image difference between 1080P and 720P. Those that can are typically expensive production monitors or projection systems. Also, current HDTV camcorders and some broadcasters horizontally sub-sample the video, further reducing any spatial resolution advantage of originating in 1080. Thus, the effective and usable spatial resolution advantage of the 1080 format over the 720 format appears to be minimal for many uses. Also noted is that 1080P@24/30 exhibits substantial flicker if displayed in its native format. More likely, 1080P@24/30 would have to be converted to 1080I@30 for display, thus losing some of the benefit of progressive scanning. Another solution could be to use a more complex type of video monitor, which refreshes the display at a higher rate than the actual frame rate.

The capability of the 720P@60 format to provide 60 progressively scanned frames per second is a very important consideration. Many researchers and operational groups have expressed a preference for a high television frame rate, and as well for progressive scanning. 720P@60 provides double the temporal resolution of the 1080P@30 format. This attribute is very useful in that it allows this format to capture twice as much information about fast moving events. Since many available HDTV monitors can already display 720P@60 in it’s native format, all of the temporal as well as spatial information captured by this format can be used.

The DTVWG studied some practical equipment considerations. Currently, there is a single source of cameras for 1080P@24/30, and two manufacturers of video recorders that operate in the format. There are four major manufacturers of 720P@60 cameras, and two with video recorders in the format. Available routing and distribution equipment can support either format. Almost all signal processing, test and production equipment available can operate in 720P.

With respect to choosing the 1080P@24/30 format, one manufacturer indicates that there is a degree of backward compatibility to their existing formats afforded with respect to an ability to playback recordings of interlace scan SDTV and HDTV material on proposed 1080P@24/30 equipment. An opinion supporting this approach has been expressed due to this proposed capability to play old tapes on newer equipment. The DTVWG does not consider this to be a significant factor due to the limited amount of NASA owned interlace scan HDTV equipment. The DTVWG also believes it will more likely be desired to play any existing interlace scan recordings, either standard or high definition, on native format equipment and perform sophisticated motion compensated de-interlacing and any needed up conversion in a separate processor to more effectively transcode this material to a progressive scan high definition format for further production. Based on discussions with two major manufacturers of HDTV equipment, it is highly unlikely future 1080P@60 equipment will provide any such backward compatibility. The DTVWG assumes that some temporal and/or spatial transcoding will be required to convert any existing material to 1080P@60, regardless of which interim HDTV format is chosen. The overall costs associated with the implementation of either the 720P or 1080P format are expected to be similar.

Another consideration was looking at which HDTV formats are being adopted by others. Some broadcast networks have chosen 1080I@30 as their standard while others have chosen 720P@60. No network has chosen 1080P@30. The use of the 1080P@24 format is being considered for electronic cinema production as a video replacement for motion picture film. The ITU has issued a standard which establishes 1920 x 1080 as a common image format. However, the ITU has recently begun the process of adopting 1280 x 720 as another common image format. Other U.S. Government agencies, most notably the Department of Defense, have standardized on 720P@60. Although there was no clear guidance derived from this particular study, any influence of this factor would seem to lead NASA to follow the choice of other U.S. Government agencies.

It is the opinion of the DTVWG that the temporal resolution advantage of 720P@60 would generally be of more value for a broader range of NASA motion imagery applications than any usable spatial resolution advantage of 1080P@24/30. As an interim standard format, 720P@60 provides progressive scanning, the highest available frame rate and much higher spatial resolution than standard NTSC video. The only aspect sacrificed is the noted, but perhaps not completely usable, higher spatial resolution of 1080P. The DTVWG also considers 720P@60 to be a suitable permanent HDTV format if 1080P@60 never becomes practical. As a result, the DTVWG has selected 720P to be the initial NASA HDTV standard picture format. The NTSC compatible field rate of 59.94 Hz, rather than the integer rate of 60, has been initially chosen to facilitate real time down or up conversion to or from the legacy format.

SDTV

The DTVWG acknowledges that traditional interlace scan, 525 line, 29.97 frame per second video will be a part of NASA imaging systems for many years to come. Although progressive scan video has been demonstrated to be superior, the continued use of the vast amount of existing equipment as a source of NASA video imagery cannot be excluded. In recent years, acquisition and production equipment has been commonly available which digitally represents this originally analog standard, typically using 720 X 483 (or more) active pixels. Note that this SDTV acquisition and production format differs slightly from any of the ATSC distribution formats in that it uses 720 pixels per horizontal line, rather than 704 or 640 (square pixel). This is not really a problem or a constraint, as the number of horizontal pixels would normally be resized as needed within a broadcast distribution encoder. Digital 525-line acquisition and production equipment usually conforms, or can be readily adapted to, the SMPTE 259M Serial Digital Interchange (SDI) Standard. There are many NASA video requirements that can continue to be adequately satisfied using this format. Thus the digital representation of traditional 525 line interlace scan video, 480I at a frame rate of 29.97 Hz, is to be the NASA SDTV standard picture format.

There are several variations of SDTV standards which specify a wide 16:9 image aspect ratio instead of the traditional 4:3. It is presumed that wide aspect SDTV would be useful for display on future wide aspect monitors and could also be more suitable for up-conversion for use in HDTV production. As an option to the 4:3 aspect ratio, the use of 16:9 capable SDTV systems, which use either an anamorphic squeeze technique or which black out upper and lower portions of a 4:3 frame, are allowed under this standard. It is also recommended, but not required, that newly acquired SDTV cameras be capable of operation in both the 4:3 and the 16:9 image aspect ratios.

There are progressive scan SDTV standards available which have demonstrated superior performance to interlace scanning. However, these systems are not yet fully developed and only a limited amount of progressive scan SDTV equipment is currently available. The members of the DTVWG also feel that adopting a progressive scan STDV standard may be a confusing and unneeded intermediate step between interlaced scan SDTV and the progressive scan HDTV standard. Thus, progressive scan SDTV systems are not initially a part of this standard. The possible future incorporation of progressive SDTV into this standard will be periodically reviewed as that format develops.

APPENDIX B

DISCUSSION OF VIDEO/AUDIO SIGNAL SAMPLING REPRESENTATIONS AND COMPRESSION FOR RECORDING AND DATA TRANSFER

Video Signal Sampling and Compression

There are existing signal standards for the transfer of uncompressed DTV. SMPTE 292M-1996 is the High Definition Serial Digital Interface (HDSDI) standard for HDTV and uses a data transfer rate of approximately 1.5 Gbps. SMPTE 259M-1997is the Serial Digital Interface (SDI) standard for SDTV and nominally transfers at a rate of 270 Mbps but can also be used at 360 Mbps.

There are many video signal sampling structures used to digitize video. These structures are used to reduce the amount of raw image data to be processed without severely affecting the image content. Generally, the chroma (color) information is not sampled at the same resolution as the luminance (black & white) portion of the picture. The human eye perceives most resolution from luminance information. This allows color information to be sub-sampled, compared to luminance, without an apparent loss of image detail. As image luminance information and information in the green color spectrum is almost equal, luminance can be used to derive the green information. Red and blue information is then often sub-sampled to reduce overall bandwidth requirements. There are sampling structures that perform full bandwidth sampling, but these are primarily used for still or computer graphics imaging systems. This type of sampling is expressed as 4:4:4, indicating that within a 4 X 4 block of luminance pixels, there is also a 4 X 4 block of both red and blue. For production video systems, 4:2:2, with a 4 X 4 luminance sample and two 2 X 2 blocks of red and blue is the standard. The sampling method used for ATSC transmissions, satellite broadcasts and Digital Versatile Discs (DVDs) is 4:2:0, which skips every other line of color samples. 4:2:0 sampling is acceptable for viewing, but not for acquisition, contribution or production. Acquisition formats sometimes use less than 4:2:2, but always perform color sampling on every line of video. 4:1:1 and 3:1:1 (18:6:6) are common sampling structures for acquisition formats. 4:1:1 is used by some SDTV systems such as DVCAM and DVCPRO. 3:1:1 is the sampling structure used by the Sony HDCAM format. These formats appear to provide a good compromise between resolution and bandwidth requirements for acquisition systems. The most important factor in sampling video for acquisition, contribution or production is to perform some degree of chroma sampling on every scan line.

Video compression for DTV will also use multiple standards, depending upon the specific requirements and application. Most video compression systems in common use, including MPEG, are based on the use of some form of Discrete Cosine Transform (DCT) encoding. Current systems for compressing DTV operate at data rates that range from less than 12 to 270 Mbps for HDTV and from less than 3 to 100 Mbps for SDTV. Available equipment for acquisition and production uses a variety of video compression techniques so attempting to establish specific agency standards for these systems is not practical. The compression used for contribution feeds and signal distribution is primarily MPEG-2 which is to be the NASA standard for these systems.

In order to maintain high quality, production systems must use higher data rates and compression ratios of 5:1 or less on non sub-sampled or resolution filtered video using 4:2:2 sampling. For acquisition systems, it is often necessary to use somewhat more compression than production equipment. A HDTV signal compressed to about 32-44 Mbps can be used as a contribution source, such as for media release or for input to production systems. This also represents a good range of target rates so that E-3 (34.368 Mbps) and T-3 (44.736 Mbps) long haul transmission services can be used. DTVWG tests have shown that low motion NASA SDTV can be compressed as low as 8 Mbps and still be used as a contribution source. Compressing a HDTV signal to 19.4 Mbps, or less, using the ATSC A/53 transmission standard results in a picture which is suitable for real-time viewing, but which has lost too much information to be usable as a contribution source for production. Tests have shown that the viewing quality of 720P can be adequate with average rates of 12 Mbps and lower. Low motion SDTV compressed as low as 3 Mbps can still provide good viewing quality. Whenever possible, a higher than minimum data rate should be used.

Data word length refers to the number of bits used to represent the voltage level of a signal sample. In all cases, the minimum word length for NASA DTV systems shall be 8 bits. The formats of the SDI and HDSDI standards allow the use word lengths up to 10 bits. Use of more than 8 bit words to represent a signal sample provides a higher fidelity video signal with a better signal to noise ratio. Equipment that uses a word length of 10 bits or more is highly recommended for production systems and may also be used for acquisition or contribution systems. Most available distribution systems and media use 8 bit words, which shall be the NASA standard for the distribution of signals, programs and media for final viewing.

Video Recording Formats

It is expected that tape, disk and solid state formats will be used for recording DTV and that there will be multiple variations of each type. Video tape recording formats will probably be restricted by the signal sampling and compression designs of specific vendor equipment. Data tape, solid state or disk based formats should be more flexible regarding signal sampling and compression choices, depending more on how the compressors are integrated to the system design. A vendor that packages a codec with his system may only offer support of certain compression schemes. However, there are also currently several data tape system and video server vendors who market their products as a general purpose recorder able to accept almost any data format.

There are currently five existing or announced digital video tape recording formats that support HDTV. Sony formerly made a 1" reel to reel uncompressed HDTV recorder, the HDD-1000, but it is no longer manufactured. The Philips/YEM D6 format recorder is the only uncompressed HDTV recorder currently on the market. Panasonic produces the HD-D5. The D5 was originally designed as a SMPTE 125/259M recorder for standard definition component serial digital video at 270 Mbps. With the addition of a codec, which has SMPTE 292M inputs and outputs, the D5 becomes a HDTV intra-frame recorder. There is no sub-sampling of luminance or chroma in HD-D5. Sony makes HDCAM, which is a 140 Mbps, 1080 line based HDTV recording system. HDCAM initially captures a 4:2:2 sampled picture at full 1920 X 1080 resolution and then performs sub-sampling[1]. Horizontal resolution is reduced from 1920 to 1440 pixels in luminance and from 960 to 480 pixels in each of the primary color channels. The end result is a picture that is sampled at 18:6:6 (3:1:1) based on a 1440 X 1080 picture. Panasonic has demonstrated an acquisition format, DVCPRO-HD, which is similar to HDCAM in some respects. This recorder uses ¼" tape and is capable of working in both interlace and progressive modes.

[1] L. Thorpe, F. Nagumo, K. Ike, "The HDTV Camcorder and the March to Marketplace Reality", SMPTE Journal, 107:164-177, March 1998

JVC has announced the D9-HD (Digital-S100) tape format. This unit has the same electrical characteristics as DVCPRO-HD, but uses a ½" tape format. Formats which meet NASA DTV standards are listed later in this appendix.

SDTV video tape recording formats are also evolving quickly. In recent years, several new formats have been introduced. Other new formats have been announced or are expected to be introduced to handle all the SDTV formats available. The most common signal interface for SDTV digital recorders is SMPTE 259M. There are other available interfaces, such as Institute of Electrical and Electronic Engineers (IEEE) 1394 (AKA Firewire and iLink). As of now, IEEE 1394 is primarily used as an interface between DV based acquisition/recording equipment and non-linear editors. IEEE 1394 is not currently capable of being routed over long distances (25 feet maximum), which precludes its use as a primary interface for distribution. Formats which meet NASA DTV standards are listed later in this appendix.

A primary issue with both SDTV and HDTV acquisition formats which use less than full resolution and other than 4:2:2 sampling such as DVCAM, HDCAM and DVCPRO-HD, is the inability of these formats to withstand multiple decoding and re-encoding cycles without degrading the image. By definition, the process of encoding a video signal eliminates some of the original image information. The more an image is compressed, the more information becomes irretrievably lost. Performing successive decode and re-encode cycles, as is done when transferring a signal between devices that use compression, will result in picture degradation. If the production processing needed to fulfill a particular video requirement is limited to simple cuts-only editing and duplication, then using an acquisition format to produce a video product is acceptable. Studio versions of acquisition recorders have "dub" mode capability, which allows a bit-for-bit clone of the original material to be made when editing and duplicating. However, complex video production incorporating animation, graphics and other effects often requires multiple cycles to and from tape, even when non-linear editing is employed. Manufacturer tests from Panasonic, and anecdotal information from Sony and Turner Entertainment indicates HDCAM and DVCPRO-HD begin to develop compression artifacts starting with the 5th decode/encode cycle. Testing by Turner Entertainment indicated that a HDTV recorder that does not sub-sample luminance and chroma and which keeps compression at 5:1 or less, showed no compression artifacts after 20 decode/encode cycles.

Currently available component digital video tape recording formats that meet or exceed the NASA standard for *acquisition* systems include:

HDTV: HD-D5, D6, D9-HD (Digital-S100), DVCPRO-HD.

SDTV: D1, D5, D7 (DVCPRO), D9 (Digital-S), Digital 8mm, Consumer DV, DVCAM, DVCPRO-50, Digital Betacam, Betacam-SX, MPEG-IMX.

Currently available component digital video tape recording formats that meet or exceed the NASA standard for *production* systems include:

HDTV: HD-D5, D6.

SDTV: D1, D5, D9 (Digital-S), DVCPRO-50, Digital Betacam, MPEG-IMX.

Audio Signal Sampling and Compression

The digital audio production standard is AES-3. AES-3 defines an uncompressed stereo audio signal with an approximate data rate of 3 Mbps. Since there are currently no video tape recorders with more than 4 channels of audio, a technique for adding additional production grade audio tracks to existing digital audio tracks to allow 6 or more channels of sound is needed. A system currently available to accomplish this is Dolby E, which is expected to be adopted as a SMPTE standard. One significant feature of Dolby E is that the interface to other equipment is at the normal AES-3 level. Using AES-3 as a common standard will allow Dolby E to be added without modification to existing digital audio systems.

The digital standard for audio that accompanies a long haul contribution video signal, such as when transmitted over a satellite, is MPEG Layer 2. This compression method can incorporate digital audio input signals sampled at several rates, including 32, 44.1 and 48 KHz. Using this method, the audio data rate can be reduced significantly and still maintain quality suitable for production use. It has been demonstrated that 16 bit, 48 KHz sampled audio can be reduced to 128Kbps with no readily detected change from the original signal.

The FCC standard for audio to accompany broadcast digital video is Dolby AC-3 (also referred to as Dolby Digital). AC-3 is a system for multiplexing and compressing 5 full bandwidth audio channels and 1 low frequency effects (subwoofer) channel into a single 384Kbps digital signal. The 5 full bandwidth channels are: 1. Left Front 2. Center Front (Dialog) 3. Right Front 4. Left Rear Surround 5. Right Rear Surround. The low frequency effects channel covers a frequency spectrum of approximately 20 -120 Hz. Because of the reduced bandwidth of the sixth channel, this is often called a 5.1 channel sound system.

AC-3 encoded audio cannot be used for production. The AC-3 signal has been processed such that it is not possible to decode the sound into 6 discrete channels of sufficient fidelity for production. AC-3 processing takes advantage of many psycho-acoustic characteristics of human hearing to reduce bandwidth. The result is that individual channels will often be missing large amounts of audio information, based on the practice that the lack of sound in one channel is being masked by another sound on another channel.

APPENDIX C

DISCUSSION OF INTERFACES

Interfaces for DTV is an area within the video industry that is not completely settled. As this situation becomes more stable with the maturity of regular DTV program production and distribution, it will be possible to establish interface standards for NASA. Listed below are examples of the information needed to specify interfaces:

- Electronic Medium
  - Satellite
  - Terrestrial

- Recorded Medium
  - Video Tape Formats
  - Disc or Other Video Media Formats

- Signal Characteristics
  - Physical Interface
  - Electrical Interface
  - Signal Protocol
  - Transmission Type
  - Transmission Protocol

Interfaces for DTV systems internal to NASA will need to be defined for several areas. One of these is between systems for receiving from or for transmitting to spacecraft and systems that provide ground video distribution and processing services. As spacecraft such as the Space Shuttle and the International Space Station develop DTV capabilities, those systems will need to provide interfaces compliant with the ground DTV system standards. This rule will also need to apply to other NASA program or project aircraft, test facility and laboratory video as well. If particular imaging requirements make the use of non-standard or unique video systems necessary, the signals generated by these systems will need to be converted in order for these projects to be able to use the video recording, production and distribution services provided by the standards based ground infrastructure. This includes services to support the distribution of information as required by the NASA Charter. Programs or projects that use non-standard video methods will probably also need to provide the equipment used to distribute, record and display that imagery in its native format. Another internal area needing DTV interface definition is for the transfer of video between NASA Centers. While the responsibility for providing inter-center video distribution services belongs to the NASA Integrated Services Network (NISN), the technical specifications for these services will be defined by the DTVWG and used by all of NASA to assure a quality DTV interchange capability.

Definition of interfaces for the transfer of DTV external to NASA will also be necessary. External interfaces include other government agencies, NASA partners such as CSA, ESA, NASDA and RSA, universities, industry and the news media. In many cases, this will only require informing those organizations in which picture format NASA DTV will be distributed, but in others it will require negotiating specific signal conventions, formats or conversion responsibilities.